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Innovative treatments to enhance skin colour and reduce scab in table potatoes

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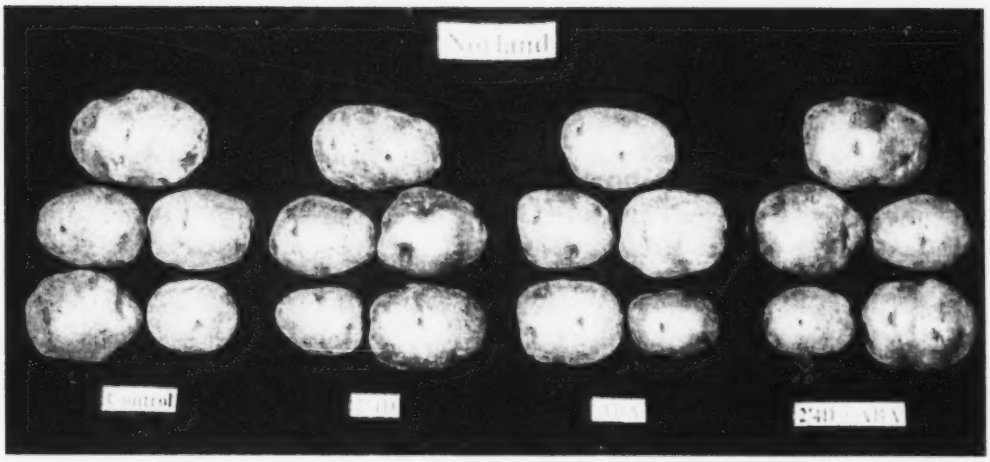

Innovative Treatments to Enhance Skin Colour and Reduce Scab in Table Potatoes

March 2010

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Abstract

A uniform dark red skin color is highly desirable in table potatoes, however the color of the most popular red-skinned cultivar (cv Norland) is highly variable and tends to fade during storage. At present, there are no production methods that will reliably enhance the skin color of Norland potatoes and as a consequence growers frequently receive less-than-otimum prices for their Norland crop. Preliminary work conducted by the U of S and others suggests that the skin colour of red potatoes might be improved by applying non-toxic dosages of the auxin type herbicide 2,4-D or long lasting analogs of the naturally occuring hormone abscisic acid (ABA) at key stages in crop development. In 2008 and 2009, these plant growth regulators (PGRs) were applied to Norland and Peregrine (a new darker red variety) potatoes at the tuber set stage. The ABA analogs did not have any consistent impact on yields, skin color or disease reaction. Although the 2,4-D treatments altered the appearance of the foliage, they had no consistent impact on yields but did cause a significant reduction in the avergae tuber size. The 2,4-D treatments appeared to enhance skin color both at harvest and after extended cold storage. The degree of color change varied with the year, the rate of 2,4-D applied and the cultivar being treated. The impact of the PGR treatments on tuber appearance was often but not always regarded favorably by consumers. The 2,4-D treatments also reduced levels of infection by common scab, but occassionally increased grade out to powdery scab. This supplementary effect of the 2,4-D treatments was less pronounced in the white-skinned cultivar Atlantic which suggests that the 2,4-D treatment effects on scab tolerance may be at least loosely linked to its impact on skin color.

Project Background

A uniform dark red skin color is highly desirable in table potatoes, however the color of the most popular red-skinned cultivar (cv Norland) is highly variable and also tends to fade during storage. The research literature indicates that many factors can influence the accumulation of the anthocyanins and xanthophyl pigments that produce the red color in the skin of potatoes. Genetics are the most important, with skin color representing a highly heritable characteristic in potatoes. One of the primary objectives of potato breeding programs in Western Canada is to develop new cultivars with superior red skin color relative to the present industry standard – Norland. In 2002, the Saskatchewan Seed Potato Growers Association (SSPGA) became the sole agent for the newly released cultivar Peregrine Red. The key attribute of this AAFC Lethbridge cultivar is its superior skin color relative to Norland. Not only is Peregrine Red darker and more uniformly red than Norland, but it also tends to hold its color better during longterm storage. While yields of Peregrine Red are equal to or superior to Norland, it is later maturing and has a smaller average tuber size. The major limitation to Peregine Red that has limited its acceptance by the industry is that it is more susceptible to common scan (*Streptomyces scabies*). This persistent soil-borne disease is widespread in commercial potato fields across Saskatchewan. While scab has no impact on crop vigor, yields or eating quality, the scab lesions reduce the visual appeal of the tubers. Tubers with more than 5% of the surface area affected by scab are considered to be unmarketable and must be graded out. At present there are no crop

protection techniques or products that provide a significant degree of protection against common scab.

Preliminary work conducted by the U of S (www.usask.ca/agriculture/plantsci/vegetable/potato/pagronomy.htm#24D) suggests that the skin colour of red potatoes might be enhanced by applying non-toxic dosages of the auxin type plant growth regulator (PGR) 2,4-D. to the foliage of the developing crop. While 2,4-D is not registered for use in potato crops as a herbicide, it is licensed in the United States to enhance the skin color of potatoes (Fults et al 1950; Nylund 1956; Rosen et al 2009). The general recommendation is for growers to apply 2.5 fl. oz/a of the low volatility ester formulation of 2,4-D to their crop at the stage where the flower buds are just beginning to form. The 2,4-D treatment is then repeated two weeks later. The onset of flowering is an easy to identify indicator that the crop is just beginning to set tubers. While we have not been able to find any studies that have addressed how time of application impacts the efficacy of the 2,4-D treatments, it is well known that the tuber set stage of development is very sensitive to environmental factors, crop management variables and disease. Tuber set takes about 2 weeks, meaning that the entire tuber set period is covered by the two applications of PGR spaced two weeks apart.

While licensing of 2,4-D for colour enhancement in red-skinned potatoes is being considered in Canada, the PMRA has not yet completed the required testing for 2,4-D residue levels in the harvested crop.

Exposure to low temperatures is known to enhance the accumulation of red pigments in crops like grapes. Potato growers also note that skin colour in their crop seems to be "washed out" in years where protracted hot weather has necessitated extensive irrigation. Exposure of plants to low temperatures triggers the production and/or accumulation of a number of compounds, including another plant growth regulator – abscisic acid (ABA). California grape growers have found that application of ABA can be used as a substitute for cold weather as a means for improving the red skin colour in their crops (Cantin et al 2007; Peppi et al 2006).

Dr. S. Abrams of PBI-NRC Saskatoon has developed a range of synthetic ABA analogs. In tests with other horticultural crops (Sharma et al 2005 and 2006) we have found that these ABA analogs are more powerful and longer lasting that standard ABA. As ABA is a naturally occurring compound, safety issues should not represent a major impediment in efforts to register the ABA analogs for use in food crops.

This project was designed to test the potential efficacy plant growth regulators as a means of enhancing skin color of red-skinned potato cultivars under Saskatchewan growing conditions.

Materials and Methods

A preliminary trial was conducted in 2007 at the Department of Plant Sciences Potato Research plots in Saskatoon Saskatchewan. The site features a sandy loam, pH 7.8, EC < 1 dS, with 4% O.M. Skin colour has been less than ideal at this site in previous crops. This field harbours insufficient common scab to allow for any evaluation of the impact of the PGR treatments on this disease.

The cultivars tested were;

Norland – the industy standard for red-skinned table potatoes on the Canadian Prairies.
Peregrine – a relatively newly released cultivar licensed to the SSPGA. Peregrine has a darker red skin color than Norland and is though to be less prone to color fading during storage.

The trial was conducted utilizing standard potato production practices. The field was fertilized according to industry recommendations. Weeds were controlled by tillage and the application of pre and post-emergent herbicides. The trial was planted in mid-May using cut certified seed, with the seed pieces spaced 20 cm apart in the row, with 1 m between rows. The trial used a split plot design (spray treatments as main plots and cultivars as sub-plots), with the treatments laid out in a randomized complete block design (N=3). Each treatment row was 8 m long. The crop was hilled prior to emergence and again just prior to row closure. An overhead irrigation system was employed whenever soil moisture potentials dropped below –50kPa. About 25 cm of rainfall was received during the 2007 growing season. This rainfall was supplemented by about 15 cm of irrigation, for a total of 40 cm of water.

The timing of application of the growth regulators as well as the rate applied was based on previous research, (see http://www.usask.ca/agriculture/plantsci/vegetable/potato/pagronomy.htm#24D), as well as label recommendations for the 2,4-D. The first application was made as the flower buds were just beginning to form. This coincides with the tubers just beginning to form. The second application occurred 10 days later, at which time both cultivars were in full flower. The PGR's were applied prior to 10 a.m. utilizing a CO_2 powered small plot sprayer equipped with a 80-02 flat fan nozzle. The sprays were applied in the equivalent of 80L water/a. This spray volume allowed for very thorough coverage of the leaves. Conditions were calm and sunny on both spray dates. The crop was not watered for at least 3 days after application of the PGR's and there were no rain events within 24 h of treatment.

The treatments used in the 2007 trial were ;

1) 2,4-D as a LV ester – applied at the recommended rate of 2.5 fl.oz/a.
2) ABA analog – PBI 365 is a longer lasting and more potent analog of naturally occurring ABA. The PBI 365 was applied at 10^{-4} M concentration. In previous studies with other horticultural crops, this concentration of PBI 365 had exerted strong effects on plants – specifically, the ABA treatment had closed the stomata, slowed crop water use and eventually acted as a growth inhibitor (see Sharma et al, 2005 and 2006).
The PBI 365 was provided by Dr. Sue Abrams of PBI/NRC, Saskatoon, SK.
3) 2,4-D + ABA – full rates of both chemicals applied as a tank mix
4) Control – sprayed with water alone.

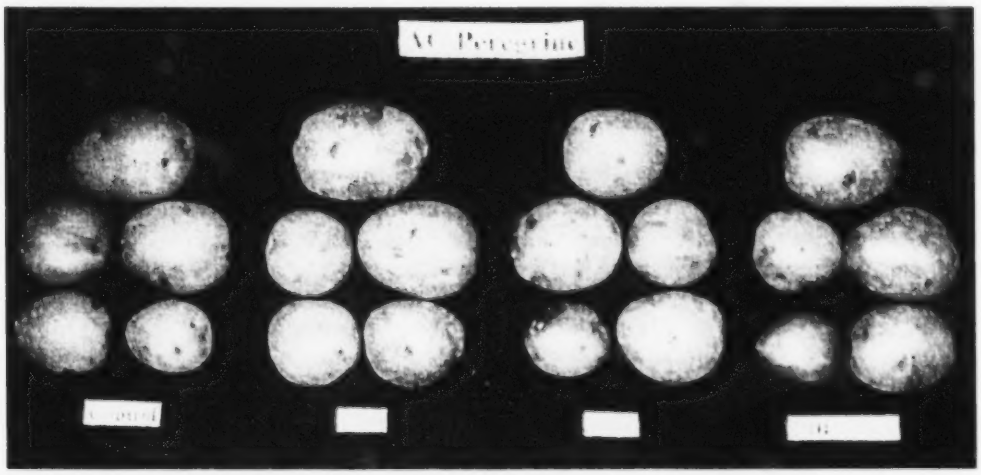
Crop health status was monitored both prior to and after the spray events. In early September the plots were desiccated using Reglone (diquat) and then flailed 10 days later. The plots were machine harvested and then held in a darkened 15°C storage. The crop was weighed and graded within 3 weeks of harvest and the potatoes were then held in a darkened 8°C storage to simulate standard early season storage conditions for table potatoes. After six weeks of cold storage, 25

potatoes randomly chosen from treatment of each cultivar were washed and their skin color was evaluated both visually and using a Hunter Lab colorimeter. The visual assessment involved having 8 trained staff ranking the samples (darkest to lightest) for relative degree of red colour. The samples used for this evaluation consisted of 5 randomly selected washed potatoes. The colorimeter was used to measure **L**, **a**, **b, a/b** (hue angle) and **chroma** values for each tuber. The **L** values (0-100) are a measure of skin lightness; the larger the **L** value the lighter the skin. The **a** values represent the relative red-green hues of the potato skin; the larger the **a** value the redder the skin. The **b** values measured the relative yellow-blue hues on potato skin; the larger the **b** value the yellower the skin. **Hue angle** values (arctan b/a) measured the ratio of red-green hues against yellow-blue hues. **Chroma** values (sqrt (a2 + b2) give an indication of the degree of saturation of color – the lower the chroma values the more saturated the color is. The more complex values of hue angle and chroma are considered to better represent how colors are perceived by the human eye.

2007 Results

Temperatures during the 2007 cropping season were quite unusual (May and June cool, July very hot, August cool) and many commercial growers reported problems with poor or uneven skin color in their red potatoes. The crop looked healthy throughout the year. Typical effects of foliar application of an auxin-type herbicide were apparent in the 2,4-D treatments within 3 days of spray application. The newest stems showed classic epinasty or fiddle heading but little impact of the sprays was seen lower in the canopy. Whether this reflects differences in spray exposure or differences in spray sensitivity could not be determined. The 2,4-D effects lasted about 1 week after application of the spray. There were no visually apparent effects of the ABA treatments. In trials with ABA in other crops, this product has tended to act as a growth retardant. The 2,4-D/ABA tank mix produced foliar symptoms comparable to treatment with 2,4-D alone.

Yields – the limited number of replication employed in this trial made it difficult to determine if the PGR treatments had any effect on yields. It seems clear that there were no negative effects on yields – for both cultivars the highest yields were obtained in treatments sprayed with one or both the PGR's (Table 2007-1).



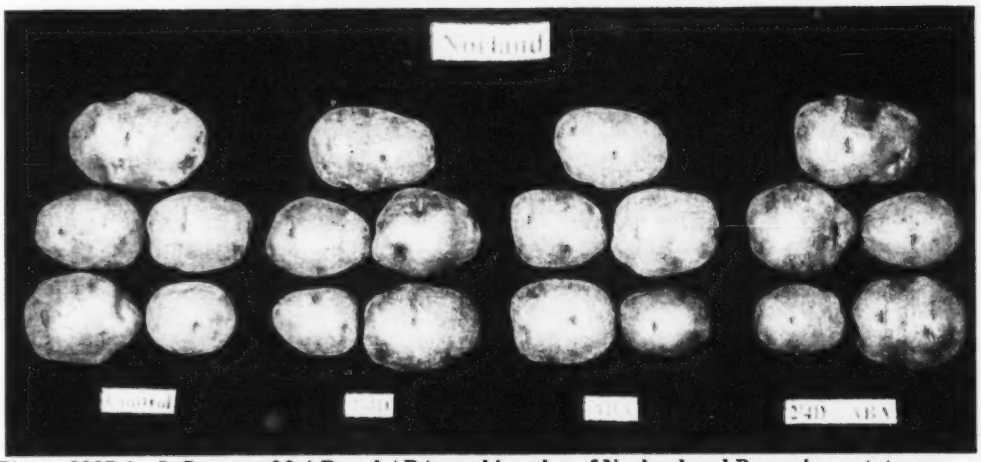


Figure 2007-1. Influence of 2,4-D and ABA on skin color of Norland and Peregrine potatoes.

The treatment effects on skin colour were visually apparent at the time of harvest and these differences were still obvious after 6 weeks of cold storage (Fig 2007-1). Based on the visual assessments made by the 8 trained evaluators, treatments receiving the 2,4-D, and to a lesser extent the ABA, appeared to be a darker red colour than the controls (Table 2007-1). Treatment effects on the skin colour were visually more apparent in Norland than in the darker skinned Peregrines. The combination of 2,4-D with ABA appeared to improve colour of the Norlands over treatment with 2,4-D alone, but this effect was not seen in Peregrine. The relative colour rankings provided by the 8 observers were very consistent, but are nonetheless subjective.

The Hunter colorimeter provides a method of objectively evaluating colour. The colorimeter readings were extremely stable from tuber to tuber (see the low CV% values)(Table 2007-1), indicating that the observed treatment effects on colour were relatively consistent and that the colorimeter reading were highly reproducible.

Although the skin color of the two cultivars was clearly different, the colorimeter readings indicated that they responded in a similar manner to treatment with the PGRs. In both cultivars, treatment with the PGR decreased the **L** values – indicating that the skins of PGR treated tubers were darker than the controls (Table 2007-1). This effect was not statistically significant for the darker skinned Peregrine, but was significant in the Norland. In both cases, the darkest skin colors (lowest **L** values) were seen when the ABA was combined with 2,4-D. There was only a marginal effect of the treatments on the **a** values, with the **a** values of Peregrine treated with ABA being higher (redder) than the controls. The apparent lack of enhancement of the red aspects of the skin color by the PGR treatments ran contrary to expectations. By contrast, the **b** values were strongly influenced by the PGR treatments. In both cultivars, the highest **b** value (least blue in the skin) was seen in the controls, while the lowest **b** values (most blue in the skin) occurred when ABA and 2,4-D were applied as a tank mix. **Hue angle** represents the balance between red/green and blue/yellow. A low hue angle represents a preponderance of red and blue tones in the skin color, with this mixture appearing purple. In both cultivars, the treatments receiving 2,4-D, either alone or mixed with ABA had a lower hue angle (more purple color) than the controls. The **chroma** values of both cultivars were reduced by the 2,4-D treatments. Low chroma values indicate a high degree of saturation or high intensity of the colors being measured.

Table 2007-1. Influence of plant growth regulators on yields and skin colour attributes of Norland and Peregrine potatoes in 2007.

	Yield	Visual Rank[z]	L-value	a-value	b-value	Hue angle	Chroma
			F-Values				
Cultivar (C)	0.32	**	***	0.69	***	**	**
PGR (T)	0.77	**	*	0.24	**	**	**
C*T	0.68	*	0.84	0.50	0.67	0.84	0.52
CV%	16	21	2	5	5	9	8
			Peregrine				
			F-Values				
PGR	0.87	**	0.69	*	**	*	**
			Means				
	(T/ha)	**(1-4 rank)**					
2,4-D + ABA	55.4	3.25 a	34.1	11.6 ab	5.9 c	0.47 c	13.0 b
ABA	59.2	2.25 b	34.7	11.9 a	6.6 b	0.51 b	13.6 a
2,4-D	52.3	3.25 b	34.6	11.0 b	6.1 c	0.51 b	12.6 c
Control	54.0	1.25 c	35.0	11.2 b	7.1 a	0.56 a	13.4 a
Avg	**55.2**	**2.5**	**34.6**	**11.4**	**6.4**	**0.51**	**13.1**
			Norland				
			F-Values				
PGR	0.34	**	*	0.80	**	**	*
			Means				
	(T/ha)	**(1-4 rank)**					
2,4-D + ABA	55.6	3.50 a	35.6 b	11.6	6.4 c	0.51 c	13.2 b
ABA	49.9	2.25 c	36.8 a	11.3	7.3 ab	0.57 b	13.4 ab
2,4-D	53.6	3.25 b	36.4 ab	11.4	6.6 bc	0.52 c	13.2 b
Control	46.8	1.00 d	37.3 a	11.0	8.0 a	0.63 a	13.6 a
Avg	**51.5**	**2.5**	**36.5**	**11.3**	**7.1**	**0.56**	**13.4**

Values within columns followed by the same letter are not significantly different at P=0.05.
[z] Ranking of 1 = lightest, ranking of 4 = darkest. N=8.
*, **,*** Indicate significant at P = 0.05, 0.01 and 0.001, respectively.

The relative ranking of the treatments obtained from the objective colorimeter evaluations of the **L** values (lightness/darkness), **b** values (blue/yellow), **hue angle** and **chroma** actually corresponded quite well with the subjective evaluations of colour made by the panel of evaluators.

The 2007 results suggest that a visually apparent degree of enhancement of skin colour can be achieved in red skinned potatoes by the application of plant growth regulators. Although the colour change was clearly detectable using both objective and subjective tests, whether the extent or the nature of the change would have actually enhanced the market value of the crop has yet to be determined. Rather than enhancing the relative "redness" of the skin, the evaluators suggested

that some of the treatments were giving the potatoes a "purple" colour. This was supported by the **hue angle** data. Whether this change is desirable is uncertain.

2008 Trial – the methods used and treatments applied in this trial were built on the results obtained in previous trials. The overall objective remains the same – to test the potential efficacy plant growth regulators as a means of enhancing the color of red-skinned potatoes under Saskatchewan growing conditions.

Materials and Methods

The 2008 trials were conducted at the Department of Plant Sciences Potato Research plots in Saskatoon Saskatchewan. Two sites were employed in 2008. The Main field was the same site as used in 2007. This site features a sandy loam, pH 7.8, EC < 1 dS, with 4% O.M. Skin colour has been less than ideal at this site in previous crops. This field harbours insufficient amounts of common scab to allow for any evaluation of the impact of the PGR treatments on this disease. The second site (Scab site) has been in a 3 year potato rotation for > 30 years and has been continuously cropped to potatoes for the past 6 years. This cropping regime has led to this site being highly infested with both common scab (*Streptomyces scabies*) as well as powdery scab (*Spongospora subterranean*). Powdery scab is less widespread in commercial potato fields in Saskatchewan than is common scab. The lesions caused by powdery and common scab look similar and grade standards do not differentiate between the two types of scab. Like common scab, powdery scab can persist in the soil for extended periods of time and is very difficult to control using standard crop management methods or pest control products. The key difference between the two types of scab is that common scab is favored by warm dry conditions, while powdery scab requires cooler, wetter conditions to thrive. Both scab organisms infect the developing tubers through the lenticels or in areas where the skin is thin. Tubers are most susceptible to invasion by both common and powdery scab early during their development – but both of these diseases appear to worsen as the season progresses as the initial lesions increase in size with time.

The soil at the Scab site is slightly lighter texture, with a higher organic matter content than in the Main field.

The cultivars tested in 2008 were again **Norland** and **Peregrine.**

Both sites were again managed utilizing standard potato production practices. The fields were prepared and fertilized according to industry recommendations. Weeds were controlled by tillage and the application of pre and post-emergent herbicides. The trial was planted in mid-May using cut certified seed, with the seed pieces spaced 20 cm apart in the row, with 1 m between rows. The trial used a split plot design (spray treatments as main plots and cultivars as sub-plots), with the treatments laid out in a randomized complete block design (N=4). Each treatment row was 8 m long. The crop was hilled prior to emergence and again just prior to row closure. An overhead irrigation system was employed whenever soil moisture potentials dropped below –50kPa.

The timing of application of the growth regulators, as well as the rates applied was based on previous research, as well as label recommendations for the 2,4-D. The first application was made as the flower buds were just beginning to form. This coincides with the tubers just beginning to form. The second application occurred 10 days later, at which time both cultivars were in full flower. The PGR's were applied prior to 10 a.m. utilizing a CO_2 powered small plot sprayer equipped with a 80-02 flat fan nozzle. The sprays were applied in the equivalent of 80L water/a. This spray volume allowed for very thorough coverage of the leaves. Conditions were calm and sunny on both spray dates. The crop was not watered for at least 3 days after application of the PGR's and there were no rain events within 24 h of treatment.

The spray treatments tested in 2008 were ;

1) 2,4-D as a LV ester – applied at the rate of 2.5 fl.oz/a. This represents the standard recommended rate for 2,4-D. This rate of 2,4-D provided some improvement in tuber color in the 2007 trial.
2) 2,4-D as LV ester at 5 fl.oz/a. This heavier dosage was used to determine if the color enhancement provided by 2,4-D was dosage dependant. It was also used to explore the impact of heavier dosages of 2,4-D on crop growth, yields and tuber configuration.
3) ABA – PBI 365 applied at 10^{-4} M concentration. This rate of PBI 365 had been shown to cause some improvement in tuber color in the 2007 trial.
4) ABA - PBI 429 applied at 10^{-4} M. In previous work (Sharma et al, 2006) we had demonstrated that PBI 429 had even more long lasting ABA effects than PBI 365 – but it often proved to be too potent, causing dwarfing and damage to the crop in a dosage dependant manner.
The PBI 365 and PBI 429 were provided by Dr. Sue Abrams of PBI/NRC, Saskatoon, SK.
5) Control – sprayed with water alone.

Crop health status was monitored both prior to and after the spray events. In early September the plots were desiccated using Reglone (diquat) and then flailed 10 days later. The plots were machine harvested and then held in a darkened 15°C storage. The crop was weighed and graded within 3 weeks of harvest and then the potatoes were held in a darkened 8°C storage to simulate standard early season storage conditions for table potatoes. After six weeks of cold storage, 25 potatoes randomly chosen from treatment of each cultivar were washed and their skin color was evaluated both visually and using a Hunter Lab colorimeter. The visual assessment involved having trained staff ranking the samples (darkest to lightest) for relative degree of red colour. The samples used for this evaluation consisted of 25 randomly selected washed potatoes. The colorimeter was again used to measure **L**, **a**, **b** and **hue angle** and **choma** values for each tuber.

The impact of the PGR treatments on potato health was evaluated by visually examining 25 randomly selected tubers from all treatment replicates grown in the scab field. The tubers were evaluated for;

a) incidence and severity of the skin lesions caused by common scab (Fig 2008-1)
b) incidence and severity of the skinlesions caused by powdery scab (Fig 2008-1)
c) incidence and severity of the lesions characterisitcs of Rhizoctonia (Fig 2008-1)

Data collected were: a) the % of the tubers examined that had significant levels of each disease, b) the proportion of the tubers that would have been rendered unmarketable due to excessive levels of the disease in question. **Canadian Food Inspection Agency standards stipulate that potatoes are no longer marketable if more than 5% of the surface area is affected by disease such as scab and Rhizoctonia.**

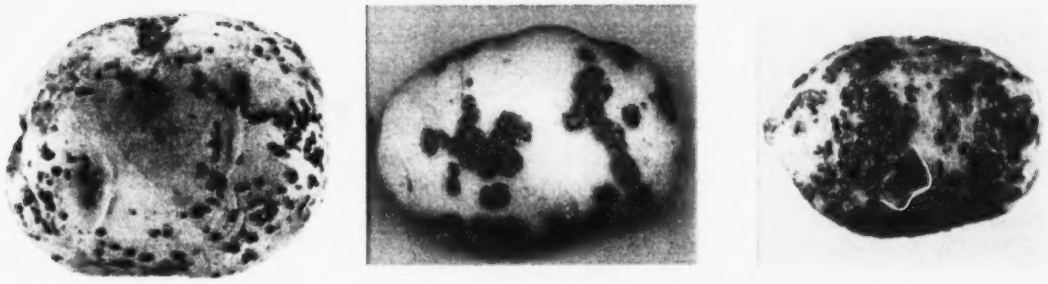


Fig 2008-1. Potato tubers infected (left to right) with; Rhizoctonia, common scab or powdery scab.

2008 Results

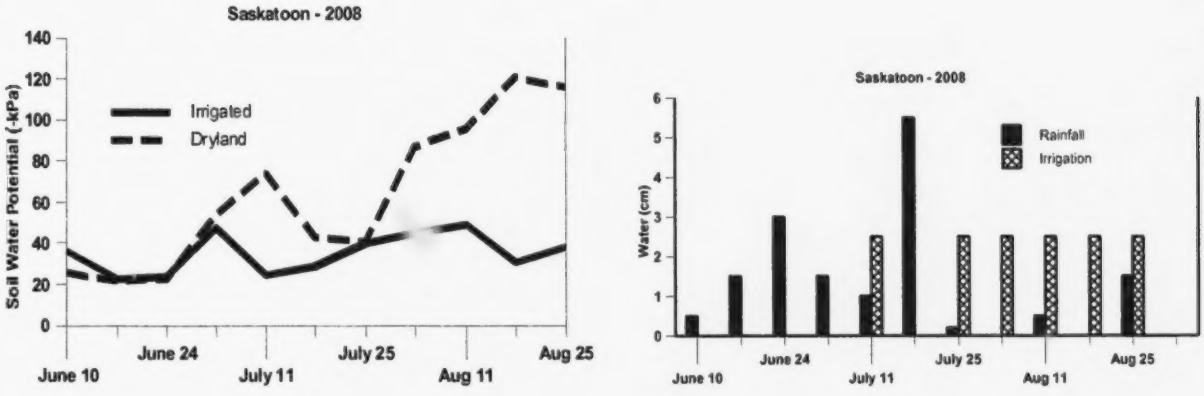


Fig. 2008-2. Soil water potentials, rainfall and irrigation events in the 2008 potato crop.

2008 Growing Season - temperatures in 2008 were below normal in May and June, about normal in July and August and above normal through the harvest period in September. About 17 cm of rainfall was received from June 1 - Sept 1 (normal = 17 cm)(Fig. 2008-2). A total of 15 cm of supplemental irrigation was applied during the 2008 growing season. The 37 cm of total moisture received by the 2008 crop consistently maintained soil moisture levels above the -50 kPa stress threshold for potatoes.

Some plants in rep 4 of the 2008 trial were damaged during the hilling process – but otherwise the crop looked generally healthy throughout the year. Within 3 days of application of the 2,4 D there were obvious changes in the appearance of the crop – the treated rows showed symptoms typically seen following exposure to auxin-like herbicides – the upper leaves became twisted and cup shaped while the petioles tended to grow more quickly than normal giving the crop a "leggy,

spindly appearance". These symptoms persisted for at least 2 weeks after the treatments were applied. There was no apparent relationship between the dosage of 2,4-D applied and the severity or duration of the symptoms described. Neither of the ABA treatments had any obvious impact of growth or appearance of the crop. This was somewhat surprising, as PBI 429 has shown profound growth inhibiting effects in other studies.

Yields – in the Main Field, the various spray treatments had no significant impact on yields of Norland (Table 2008-1). The high rate of 2,4-D reduced yields of Peregrine relative to the untreated control. In the Scab Field, there were no statistically significant treatment effects on tuber yields (Table 2008-2). There was however a trend for the 2,4-D treatments to reduce yields of Peregrine. In both fields and for both cultivars, the 2,4-D treatments caused a consistent decrease in the average tuber size.

The treatment effects on skin colour were visually apparent at the time of harvest and these differences were still obvious after 6 weeks of cold storage at which time the colour of the tubers was assessed y both a panel and using the Hunterlab. Based on the visual assessments of the crop grown in the field infested with scab, the 2,4-D treatments enhanced the colour of both cultivars – while the ABA analogue treatments had no impact on skin colour (Table 2008- 2) The relative colour rankings of the treatments were very consistent, but are nonetheless subjective.

The Hunter colorimeter provides a method of objectively evaluating colour. As indicated by the CV values, the colorimeter readings were less stable from tuber to tuber in the 2008 trial than in 2007. Whether this reflects differences in the measuring procedure or actual differences in colour variability could not be determined.

In the 2007 trial, the colorimeter readings indicated that the Peregrine and Norland responded in a similar manner to treatment with the PGRs. In the 2008 trial there was more variability in the response between the cultivars. The general level of response to the PGR treatments was also less clear than in 2007. The basis for this year to year difference in responses to the PGRs could not be determined.

In both cultivars, treatment with 2,4-D decreased the **L** values – indicating that the skins were darker than the controls (Table 2008-1). The same effect of 2,4-D on **L** values was observed in the 2007 trial. In both cultivars, the PBI 365 treatment appeared to lighten the skin colour versus the controls, while the PBI 429 treatment darkened the skin colour. The impact of the various PGR treatments on the **a** values differed for the two cultivars. In Norland, the highest **a** value was seen in the untreated control treatment, with the lowest value occurring in the PBI 429 treatment. In Peregrine, the PBI 365 treatment had the highest **a** values, while the 2.5 oz/a rate of 2,4D produced the lowest **a** values. This apparent lack of enhancement of the red (**Hunter a**) aspects of the skin color by the PGR treatments corresponds with the findings in the 2007 trial. By contrast, the **b** values of both cultivars were consistently reduced by the 2,4-D treatments – indicating that the 2,4-D treatments were increasing the relative amount of blue in the skin colour. A similar response to the 2,4-D treatments was seen in the 2007 trial. The ABA analog treatments had no impact on the **b** values of either cultivar in 2008. This differs from the 2007 trial, where **b** values of both cultivars were reduced following treatment with the PBI 365 analog. The **hue angle** represents the balance between red/green and blue/yellow. A low **hue angle** represents a preponderance of red and blue tones in the skin color, with this mixture appearing purple. In both cultivars, the treatments receiving 2,4-D had a lower **hue angle** (more purple color) than the controls. A similar effect of the 2,4-D on **hue angle** was seen in 2007. Neither of

the ABA analogue treatments had any impact on the **hue angle** values in this trial. This differs from the 2007 trial where the ABA treatment had reduced the **hue angle** in both cultivars. The impact of the PGR treatments on the **Chroma** values differed between the two cultivars. In Norland, all of the PGR treatments reduced the **chroma** relative to the controls. In Peregrine, both of the ABA analogues appeared to increase the **chroma**, while the 2,4-D treatments reduced the **chroma** values. In the 2007 trial, the 2,4-D treatments had reduced the **chroma** relative to the controls, while the ABA treatments had little impact on this variable.

Table 2008-1. Influence of plant growth regulators on yields and skin colour attributes of Norland and Peregrine potatoes in the Main Field in 2008

	Yield	**Avg size**	**L-value**	**a-value**	**b-value**	**Hue angle**	**Chroma**
				F-Values			
Cultivar (C)	0.74	***	*	***	***	0.67	***
PGR (T)	0.24	*	***	0.20	***	***	***
C*T	0.54	0.34	***	***	0.10	***	***
CV%	19%	16	8	16	26	20	15%
				Peregrine			
				F-Values			
PGR	*	**	***	***	***	***	***
				Means			
	(T/ha)	**(g)**					
Control	55.4 a	143 a	34.1 a	14.4 bc	6.8 a	0.45 a	16.0 ab
2,4 D (2.5 oz/a)	47.1 ab	104 b	30.8 c	14.0 c	5.2 b	0.36 c	15.0 b
2,4D (5 oz/a)	38.4 b	109 b	32.5 b	14.5 abc	5.6 b	0.40 b	15.5 ab
PBI 365	49.9 ab	132 a	33.4 a	15.2 a	6.8 a	0.43 a	16.8 a
PBI 429	53.1 ab	140 a	32.4 b	15.1 ab	6.8 a	0.44 a	16.8 a
Avg	**48.8**	**126**	**32.7**	**14.5**	**6.2**	**0.42**	**15.8**
				Norland			
PGR	0.95	*	***	***	***	***	***
	(T/ha)	**(g)**					
Control	48.8	164 a	32.3 bc	14.8 a	6.6 a	0.43 b	16.2 a
2,4-D(2.5oz/a)	50.0	143 b	30.6 d	14.1 ab	5.4 b	0.37 c	15.2 b
2,4-D (5 oz/a)	44.8	140 b	31.5 c	13.9 bc	5.6 b	0.40 c	15.0 b
PBI 365	49.5	164 b	34.1 a	13.6 bc	6.5 a	0.44 ab	15.3 b
PBI 429	46.4	163 b	33.1 b	13.2 c	6.7 a	0.47 a	14.9 b
Avg	**47.9**	**155**	**32.3**	**13.9**	**6.2**	**0.42**	**15.3**

Values within columns followed by the same letter are not significantly different at *P*=0.05.

[z] Visual rankings not available

*, **,*** Indicate significant at P = 0.05, 0.01 and 0.001, respectively.

Table 2008-2. Influence of plant growth regulators on yields and scab ratings (common and powdery) of Norland and Peregrine potatoes in the Scab Field in 2008.

	Yield	Avg Tuber Size	Visual Rank[z]	Common (%)	Common Severity	Powdery (%)	Powdery Severity
Cultivar (C)	*	**	*	**	**	**	*
PGR (T)	0.19	***	**	**	**	**	**
C*T	0.69	0.34	*	**	*	**	
CV%	13%	10	15	34	17	18	44
Peregrine							
F-Values							
PGR	0.27	***	**	**	**	**	**
Means							
	(T/ha)	**(g)**	**Rank (1-5)**	**%**	**Severity**	**%**	**Severity**
Control	44.2	126 ab	3.0 b	98 a	63 a	46 b	20 c
2,4 D (2.5 oz/a)	36.2	103 bc	4.0 a	40 b	2 b	89 a	58 a
2,4 D (5 oz/a)	36.1	95 c	4.2 a	28 c	3 b	87 a	42 b
PBI 365	41.1	136 a	3.2 b	94 a	61 a	55 b	22 c
PBI 429	43.0	130 a	3.0 b	96 a	61 a	59 b	28 c
Avg	**40.1**	**112**	**3.0**	**71**	**38**	**67**	**34**
Norland							
PGR	0.80	***	**	0.79	0.19	*	*
Means							
	(T/ha)	**(g)**	**Rank (1-5)**	**%**	**Severity**	**%**	**Severity**
Control	47.9	186 a	2.8 c	29	3	44 b	15 b
2,4 D (2.5 oz/a)	43.2	149 b	3.7 b	19	0	58 ab	28 ab
2,4-D (5 oz/a)	44.5	140 c	4.8 a	23	0	64 a	37 a
PBI 365	42.9	168 ab	2.3 c	21	1	58 ab	24 ab
PBI 429	44.8	168 ab	2.0 c	28	3	40 b	16 b
Avg	**44.6**	**162**	**3.0**	**24**	**1.5**	**53**	**24**

Values within columns followed by the same letter are not significantly different at P=0.05.
[z] Ranking of 1 = lightest, ranking of 5 = darkest.
*, **,*** Indicate significant at P = 0.05, 0.01 and 0.001, respectively.

Any diseases that can affect the appearance of the skin of a potato crop can negatively affect the market value of the crop. In the 2008 trial levels of Rhizoctonia were relatively light and none the PGR treatments influenced Rhizoctonia levels on either cultivar tested. By contrast, the incidence and severity of both common and powdery scab were quite high. As expected, the incidence and severity of common scab was intense in Peregrine but far less of a problem on tubers of the more resistant Norland. In the Norland, the PGR treatments had no impact on either the % of tubers affected by common scab or the severity of this disease on the infected tubers. **However, in Peregrine, the 2,4-D treatments dramatically reduced both the incidence and**

severity of the common scab problem. Grade out of Peregrine tubers to excessive levels of common scab were reduced from ca. 60% in the controls to less than 5% in the 2,4-D treatments. The degree of mitigation of the common scab was not related to the rate of 2,4-D applied. **While the 2,4-D treatments appeared to reduce the incidence of common scab on Peregrine, they drastically increased problems with powdery scab.** A similar, but more muted response to the 2,4-D treatments was seen for powdery scab levels on Norland. Neither of the ABA analogues had any impact on levels of either common or powdery scab.

In untreated rows of Peregrine, over 80% of the tubers exceeded grade tolerance for either common or powdery scab. By contrast, only 50% of the Peregrine crop would have been graded out in areas treated with 2,4-D. In Norland, the 2,4-D treatments actually increased total grade out, as they appeared to increase problems with powdery scab and provided no benefit in terms of common scab, as Norland is relatively resistant to this disease.

Color Assessment after Storage

One of the common complaints about cv. Norland is that its colour tends to fade over the duration of the winter storage period. In this trial we investigated the impact of PGRs applied during the growing period on the retention of skin colour during longterm storage.

The tubers used to assess the skin colour at 6 weeks after harvest in 2008 were then moved to standard cold storage (4°C and 95% RH) and held under those conditions until April of 2009 (5.5 months of cold storage). Few growers in Saskatchewan attempt to store red potatoes past this time of year.

The Hunterlab was used as previously described to provide an objective assessment of skin colour after extended storage. The tubers were also evaluated by a panel of 20 non-trained assessors for "redness" of the skin as well as which treatment they would be "most interested in purchasing". The Peregrine and Norland cultivars were rated separately. Redness was evaluated from most (1) to least (5). Willingness to purchase was rated by which sample the assessor would be most interested in purchasing. The "willingness to purchase" was designed to test whether the PGR treatments were actually altering the colour in a manner that consumers would find appealing. However it also had the potential to highlight any effects the PGR treatments might have had on other characteristics that influence the decision to purchase – like tuber shape and size.

Table 2008-3. Influence of plant growth regulators on skin colour and consumer preference of Norland and Peregrine potatoes after 5.5 months cold storage.

	L-value	a-value	b-value	Hue angle	Chroma	Redness[z]	Purchase preference
			Peregrine				
			F-Values				
PGR	***	0.15	***	***	***	***	***
			Means				
						Rank(1-5)	**%**
Control	35.1a	12.6	7.1a	0.52a	14.5a	3.9a	25bc
2,4 D (2.5 oz/a)	34.0b	12.7	5.9c	0.44c	14.0ab	1.4b	10bc
2,4D (5 oz/a)	34.1b	12.2	6.3b	0.48b	13.7b	1.6b	5bc
PBI 365	34.4b	12.4	6.9a	0.51a	14.3a	3.9a	0c
PBI 429	34.4b	12.5	7.0a	0.52a	14.4a	4.1a	60a
Avg	**34.2**	**12.5**	**6.6**	**0.49**	**14.2**		
			Norland				
PGR		*	***	***	***	***	***
						Rank (1-5)	**%**
Control	34.4a	12.0ab	6.8ab	0.53a	13.9a	4.4a	0b
2,4-D(2.5oz/a)	34.2a	12.2ab	6.0c	0.46c	13.7a	1.0d	45a
2,4-D (5 oz/a)	33.2b	11.0b	5.9c	0.47bc	13.1b	2.3c	4b
PBI 365	35.0a	12.2a	6.6b	0.50b	14.1a	3.5b	50a
PBI 429	34.6a	11.9ab	7.1a	0.54a	13.9a	3.8b	0b
Avg	**34.3**	**11.9**	**6.5**	**0.50**	**13.7**		

Values within columns followed by the same letter are not significantly different at *P*=0.05.

[z] Redness rating from 1 (most) to 5 (least).

% Purchase preference = % of panellists surveyed (n=20) who rated this treatment as most likely to purchase.

*, **,*** Indicate significant at P = 0.05, 0.01 and 0.001, respectively.

Results

The potatoes stayed in very good condition over the 5.5 month storage period and they retained their colours quite well. The changes in skin colour during storage as assessed by the Hunterlab were consistent for the two cultivars. Both cultivars got slightly lighter (higher **L** value), less red (lower **a** values) and more yellow (higher **b** values). The **hue angle** values increased (less red/blue and more yellow/green) while the chroma (degree of color saturation) increased. These changes correspond well with the comments made by visual assessors of stored red-skinned potatoes – they look faded and pink rather than red.

In both cultivars, treatment with 2,4-D had decreased the **L** values at harvest (darker skin) – and this effect persisted through the 5.5 month storage period (Table 2008-3). In Peregrine the ABA analog treatments also kept the skin darker than the controls during long term storage – but this effect was not seen in the Norlands. The PGR treatments had no consistent effect on **a** values

after longterm storage – this corresponds to a general lack of effect on **a** values seen at harvest. The **b** values of both cultivars had been consistently reduced by the 2,4-D treatments at harvest – and this effect persisted through the storage period. A lower **b** value indicates the treatments were increasing the relative amount of blue in the skin colour. The **hue angle** represents the balance between red/green and blue/yellow. A low **hue angle** represents a preponderance of red and blue tones in the skin color, with this mixture appearing purple. In both cultivars, the treatments receiving 2,4-D had a lower **hue angle** (more purple color) than the controls at harvest – and this effect persisted through the storage period. In Norland, all of the PGR treatments reduced the **chroma** relative to the controls. In Peregrine, both of the ABA analogues appeared to increase the **chroma,** while the 2,4-D treatments reduced the chroma values. In the 2007 trial, the 2,4-D treatments had reduced the **chroma** relative to the controls, while the ABA treatments had little impact on this variable.

Although the Hunterlab data suggested that the PGRs had a relatively limited effect on skin colors after storage, the panellists surveyed could clearly detect treatment effects. In both cultivars the panellists consistently picked the 2,4-D treated potatoes as having a darker red colour than the controls (Table 2008-3). A similar treatment effect was noted by the panellists who rated the potatoes at the time of harvest (Table 2008-2).

The decision as to which of the samples the panellists would "prefer to purchase" involves a complex blend of selection criteria, many of which would be highly subjective. This is reflected by the choice data for the potatoes after 5.5 months of storage (Table 2008-3). No one treatment emerged as superior to others based on consumer selection preference. For Peregrine, the majority of panellists selected the potatoes treated with the ABA analog PBI 429 – despite the fact that both the objective and subjective colour assessments rated it as no different from the controls. The untreated control treatment was regarded as second most desirable for Peregrine. For Norland the sample treated with PBI 365 was rated as preferable by 50% of the panellists, despite the fact that its colour was not discernibly different from the controls (Tables 2008-1 and 2008-3). These results suggest that colour may not be the primary selection criteria for tuber quality. The treatments may have been altering some other aspect of the tuber appearance in a manner that enhances their consumer appeal.

2009 Trial

The methods used and treatments applied in this trial were built on the results obtained in previous trials. The primary objective remained the same – to test the potential efficacy plant growth regulators as a means of enhancing the color of red-skinned potatoes under Saskatchewan growing conditions. The potential to use PGRs to control disease was also explored in 2009.

Materials and Methods

The 2009 trials were conducted in a manner that closely resembled the 2008 trial. The trial was again conducted at the Department of Plant Sciences Potato Research plots in Saskatoon Saskatchewan, using the same two fields (Main and Scab) used in 2008. See the report for 2008 for detailed descriptions of the two sites.

The cultivars tested in 2009 were **Norland** and **Peregrine** as in previous years, but in 2009 the white skinned processing cultivar **Atlantic** was also included in the trial. The objective of using Atlantic was to include a scab sensitive cultivar that was not red-skinned – thereby potential allowing us to separate the effect of the PGR treatments on skin color versus their effect on disease.

Both sites were again managed utilizing standard potato production practices. The fields were prepared and fertilized according to industry recommendations. Weeds were controlled by tillage and the application of pre and post-emergent herbicides. The trial was planted in mid-May using cut certified seed, with the seed pieces spaced 20 cm apart in the row, with 1 m between rows. The trial used a split plot design (spray treatments as main plots and cultivars as sub-plots), with the treatments laid out in a randomized complete block design (N=4). Each treatment row was 8 m long. The crop was hilled prior to emergence and again just prior to row closure. An overhead irrigation system was employed whenever soil moisture potentials dropped below –50kPa.

The timing of application of the growth regulators, the rates applied and the method of application were identical to 2008. Conditions were calm and sunny on both spray dates in 2009. The crop was not watered for at least 3 days after application of the PGR's and there were no rain events within 24 h of treatment.

The PBI 365 and PBI 429 were again provided by Dr. Sue Abrams of PBI/NRC, Saskatoon, SK.

Crop health status was monitored both prior to and after the spray events. Due to an influx of late blight (*Phytophthora infestans*) in mid-August the crop was flailed then desiccated in late August rather than in early Setember as had been the practice in the previous years of the trial. The plots were machine harvested in late September with the harvested tubers then held in a darkened 15°C storage. The crop was weighed and graded within 3 weeks of harvest and the potatoes were then held in a darkened 8°C storage to simulate standard early season storage conditions for table potatoes. After six weeks of cold storage, 25 potatoes randomly chosen from treatment of each cultivar were washed and their skin color was evaluated both visually and using a Hunter Lab colorimeter. The visual assessment involved having trained staff ranking the samples (darkest to lightest) for relative degree of red colour. The samples used for this evaluation consisted of 25 randomly selected washed potatoes. The colorimeter was again used to measure **L**, **a**, **b** and **hue** and **choma** values for each tuber.

The impact of the PGR treatments on potato health was evaluated by visually examining 25 randomly selected tubers from all treatment replicates grown in the scab field. The tubers were evaluated for incidence and severity of common scab, powdery scab and Rhizoctonia as described in the 2008 trial. Data collected were: a) the % of the tubers examined that had significant levels of each disease, b) the proportion of the tubers that would have been rendered unmarketable due to excessive levels of the disease in question.

2009 Results

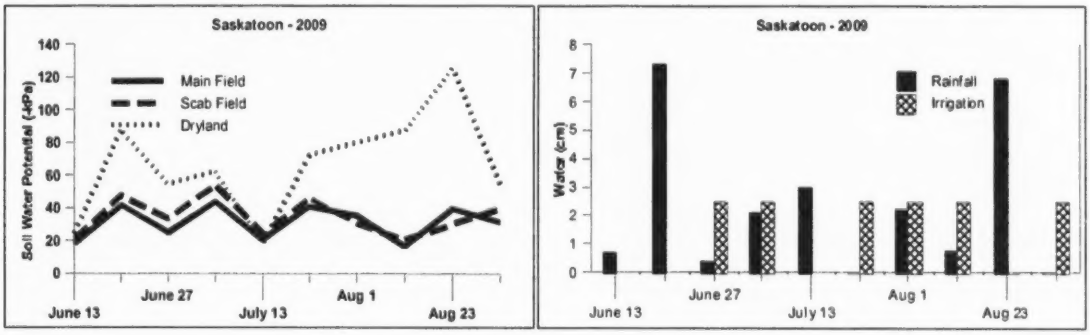


Fig. 2009-1. Soil water potentials, rainfall and irrigation events for the 2009 potato trials in Saskatoon.

2009 Growing Season - temperatures in 2009 were well below normal in May and June, slightly below normal in July and August and well above normal during the harvest period in September. While the cool temperatures would have delayed emergence and early growth, they should have been favorable during the crucial periods of tuber set and bulking. Unusually warm conditions in September facilitated top-kill and skin set but caused concerns regarding high temperatures in storage. About 23 cm of rainfall was received from June 1 - Aug 31 of 2009 (normal = 17 cm). A total of 15 cm of supplemental irrigation was applied during the 2009 growing season. The 38 cm of total moisture received by the irrigated crop consistently maintained soil moisture levels above the -50 kPa stress threshold for potatoes.

The crop in the main field was slow to establish and lacked vigor especially early in the growing season. This likely reflects the extremely dry conditions that persisted through late June at this site. Extremely dry conditions coupled with some soil compaction made hilling difficult in the Main field. The crop in the scab field appeared more vigorous and no problems were experienced at hilling time.

Due to an influx of late blight (*Phytophthora infestans*) in mid-August the crop was flailed then desiccated in late August rather than in early September as is normal proactice in Saskatchewan. Although foliar symptoms of late blight were observed in the plots, the disease did not appear to spread to the tubers.

As was seen in previous years, the effects of the 2,4D treatments were obvious within 3 days of application – the upper leaves became twisted and cup shaped while the petioles tended to grow more quickly than normal giving the crop a "leggy, spindly appearance". These symptoms

persisted for at least 2 weeks after the treatments were applied in the Main field and persisted in the Scab field for the duration of the growing season. As in previous trials there was no apparent relationship between the dosage of 2,4-D applied and the severity or duration of the symptoms described. The cv Atlantic showed fewer symptoms of the 2,4-D treatments than did Norland or Peregrine. Neither of the ABA treatments had any obvious impact of growth or appearance of the crop.

A relatively high level of soft rot was observed in the harvested tubers of cv. Atlantic – this rot was not apparent at harvest, but developed rapidly during the 6 weeks it took to grade the crop. The cause of the problem could not be readily identified. The extent of rot was similar in all treatments (ca 10%). No corresponding problems with rot were observed in the Norland or Peregrine crops.

Yields – in the Main Field, the various spray treatments had no significant impact on yields of Norland (Table 2009-1). Both the ABA treatments increased Peregrine yields relative to the control, while the high rate of 2,4-D reduced yields of Atlantic relative to the untreated control. In the Scab Field, the high rate of 2,4-D reduced yields of all three cultivars relative to the controls (Table 2009-2). The ABA treatments had no consistent impact on yields in the scab field.

Tuber colour at harvest - In the 2007 trial, the colorimeter readings indicated that the Peregrine and Norland responded in a similar manner to treatment with the PGRs. In the 2008 trial there was more variability in the response between the cultivars. In the 2009 trial the responses of the two red skinned cultivars to the PGR treatments were quite comparable.

In Norland and to a lesser extent Peregrine, treatment with 2,4-D decreased the **L** values – indicating that the skins were darker than the controls (Table 2009-1). The same effect of 2,4-D on **L** values was observed in both the 2007 and 2008 trial. The impact of the various PGR treatments on the **a** values in 2009 differed for the two red-skinned cultivars. In Norland, the highest **a** value was seen with the high rate of 2,4-D, while the lowest **a** value was seen when the low concentration of 2,4-D was applied. In Peregrine, both rates of 2,4-D reduced the **a** values relative to the controls. As a higher **a** value indicates a "redder" colour this result runs contrary to overall expectations, but corresponds with the findings from previous years. By contrast, the **b** values of both cultivars were consistently reduced by the 2,4-D treatments – indicating that the 2,4-D treatments were increasing the relative amount of blue in the skin colour. A similar response to the 2,4-D treatments was seen in both the 2007 and 2008 trials. Neither of the ABA analog treatments had any impact on the **b** vales of either cultivar in 2009 – this corresponds with the findings of 2008, but differs from the 2007 trial, where **b** values of both cultivars were reduced following treatment with the PBI 365 analog. The **hue angle** represents the balance between red/green and blue/yellow. A low hue angle represents a preponderance of red and blue tones in the skin color, with this mixture appearing purple. In Norland, the treatments receiving 2,4-D had a lower **hue angle** (more purple color) than the controls, but this effect was not seen in the darker skinned Peregrines. A similar effect of the 2,4-D on **hue angle** of Norland was seen in 2007 and 2008. As was seen in 2008, neither of the ABA analogue treatments had any impact on the **Hue angle** values in the 2009 trial. The PGR treatments had little consistent effect on the **chroma** values for the two red-skinned cultivars in 2009. The PGR treatments had a greater effect on the **chroma** values in other years of this trial.

The colour of the white-skinned Atlantics at harvest was less affected by the PGR treatments than for the red-skinned cultivars. The only statistically significant difference attributed to PGR treatment of the Atlantics was that the **a** value for the PBI 429 treated tubers was higher than the controls, indicating that this treatment made the tubers slightly "redder".

Table 2009-1. Influence of plant growth regulators on yields and skin colour attributes of Norland, Peregrine and Atlantic potatoes in the Main Field in 2009

	Yield	L-value	a-value	B-value	Hue angle	Chroma
			F-Values			
Cultivar (C)	**	***	***	***	***	***
PGR (T)	*	**	*	***	*	**
C*T	*	**	**	***	*	*
			Peregrine			
			F-Values			
PGR	*	*	**	*	0.27	*
			Means			
	(T/ha)					
Control	46.0 c	35.8 ab	15.2 a	6.9 a	0.42	16.7 ab
2,4 D (2.5 oz/a)	48.5 bc	35.5 ab	14.5 b	6.3 b	0.41	15.9 b
2,4D (5 oz/a)	49.8 bc	34.8 b	14.7 b	6.3 b	0.40	16.0 b
PBI 365	56.4 a	35.5 ab	15.6 a	7.4 a	0.44	17.3 a
PBI 429	52.8 ab	36.8 a	15.3 a	7.1 a	0.44	16.9 a
Avg	**50.7**	**35.7**	**15.1**	**6.8**	**0.42**	**16.6**
			Norland			
PGR	0.34	***	*	**	*	*
			Means			
	(T/ha)					
Control	53.3	39.7 a	14.1 b	8.8 a	0.56 a	16.7 a
2,4-D (2.5 oz/a)	55.9	36.3 c	13.7 b	6.5 b	0.44 b	15.2 b
2,4-D (5 oz/a)	52.9	37.2 b	15.0 a	6.7 b	0.42 b	16.4 a
PBI 365	50.0	39.2 a	14.1 b	8.1 a	0.52 a	16.3 a
PBI 429	54.0	39.4 a	14.5 ab	8.5 a	0.53 a	16.8 a
Avg	**53.2**	**38.4**	**14.3**	**7.7**	**0.49**	**16.3**
			Atlantic			
PGR	*	**	*	*	0.56	0.17
			Means			
	(T/ha)					
Control	44.6 a	51.3 abc	7.3 b	18.3 ab	1.2	19.7
2,4-D (2.5 oz/a)	42.6 ab	51.9 ab	7.1 b	19.1 a	1.2	20.3
2,4-D (5 oz/a)	37.9 b	52.8 a	7.1 b	19.2 a	1.2	20.5
PBI 365	45.2 a	50.5 bc	7.2 b	17.8 b	1.2	19.2
PBI 429	41.8 ab	49.2 c	7.8 a	18.0 b	1.2	19.8
Avg	**42.4**	**51.1**	**7.3**	**18.5**	**1.2**	**19.9**

Values within columns followed by the same letter are not significantly different at P=0.05.

*, **,*** Indicate significant at P = 0.05, 0.01 and 0.001, respectively.

Tuber colors after storage

The tubers used for colour assessments at harvest in 2009 were returned to cold storage (4°C and 95% RH) and the colors were evaluated again after 4 months of storage (February 2010). The tubers were still in good conditions with minimal rots or sprouting at the end of the 4 month storage period. The colorimeter data indicates that there were some slight changes in color over the storage period. For both the Norland and Peregrine, the tubers got slightly lighter (higher **L** values) while the white skinned Atlantics got darker (lower **L** values). A similar lightening of the skin colour was observed in the 2008/2009 storage trial. The **a** values for both red cultivars decreased with storage indicating a fading of the red aspects of the color spectrum – this change was also noted in the 2008/2009 trial. The **b** values of Peregrine and Atlantic both decreased during storage indicating a shifting of the color towards blue and away from yellow. By contrast, the b values of both red cultivars had increased during storage in 2008/2009. **Hue angle** of both Peregrine and Norland increased during storage indicating that the tubers were less purple than at harvest. This again corresponds with the findings in the 2008/2009 storage trial

When colors were assessed at harvest, treatment with 2,4-D had decreased the **L** values of both the red skinned cultivars, indicating that the skins were darker than the controls (Table 2009-1). This effect persisted through the 4 month cold storage period but was more significant in Peregrine than in Norland. The impact of the 2,4-D treatments on the **a** values at harvest in 2009 had differed for the two red-skinned cultivars. In Norland, the highest **a** value had been seen with the high rate of 2,4-D and this effect persisted through the storage period. In Peregrine, both rates of 2,4-D had reduced the **a** values relative to the controls at harvest, but after 4 months storage only **a** values for the high rate of 2,4-D differed from the controls. The **b** values of both cultivars at harvest had been reduced by the 2,4-D treatments and this effect persisted through the storage period. In Norland, the treatments receiving 2,4-D had a lower **hue angle** (more purple color) at harvest than the controls, but this effect was not seen in the darker skinned Peregrines. After 4 months storage, the **hue angle** for Norland tubers treated with the high rate of 2,4-D was still lower than the controls. A similar enhancement of the purple aspects of the skin color after 4 months storage was seen for both 2,4-D rates tested on Peregrine.

The colour of the white-skinned Atlantics at harvest was less affected by the PGR treatments than for the red-skinned cultivars and this general lack of treatment effect persisted through the storage period. The only exception was that during storage the **b** values for the Atlantic tubers declined significantly indicating a loss of yellow color (or an increase in blue). The degree of this color change was greater in all of the PGR treatments than in the controls.

After 5 months storage in 2008/2009 the panellists had consistently picked the 2,4-D treated potatoes as having a darker red colour than the controls (Table 2008-3). This same treatment response was seen in Norland after 4 months storage in 2009/2010, but in Peregrine the tubers in the control treatments were considered by the panellists to have the darkest red colour. This finding did not correspond with the colorimeter results which indicated that all aspects of the colour (L, a, b and hue values) of the 2,4-D treated Peregrines would suggest a darker skin colour than all other treatments including the control.

The decision as to which of the samples the panellists would "prefer to purchase" involves a complex blend of selection criteria, many of which would be highly subjective. This is reflected

by the choice data for the potatoes after cold storage in 2008/2009 and 2009/2010. No one treatment emerged as superior to others based on consumer selection preference. For Peregrine, the majority of panellists selected the control potatoes as being "most preferable" – despite the fact that both the objective and subjective colour assessments rated it as no different from the 2,4-D treated tubers. By contrast, for Norland the 2,4-D treatments were considered superior by 90% of the panellists – which corresponded to both the objective and subjective evaluations of skin colour in 2009/2010. These results, taken together with similar finding in the 2008/2009 storage trial, suggest that while colour is an important selection criterion for tuber quality, its value can be superseded by other aspects of tuber appearance. If the PGR treatments alter these aspects in a negative manner this may negate the skin colour enhancing effects we have observed following application of certain PGRs. It is important to note that we did not observe any obvious treatment effects on tuber shape. We did however note a small, but consistent, reduction in the average tuber size in the 2,4-D treatments. The change in tuber size would have had no impact on commercial grading standards for the crop, but might have been subtly influence the panellists' choice preferences. It is perhaps noteworthy that the 2,4-D treatments were not favored in Peregrine but were favored in Norland. The average tuber size of Peregrine is inherently smaller than Norland. It is therefore possible that the 2,4-D treatments were reducing the size of the Peregrine tubers below some "acceptance threshold" – while the larger Norland tubers remained above this threshold despite the size reducing influence of the 2,4-D treatments.

Table 2009-2. Influence of plant growth regulators on skin colour attributes of Norland, Peregrine and Atlantic potatoes after 4 months storage (2009/2010).

	L-value	a-value	B-value	Hue angle	Redness [z]	Purchase preference
Cultivar (C)	***	***	***	***		
PGR (T)	**	*	***	*		
C*T	**	**	***	*		
PGR	*	**	*	*	Rank (1-5)	%
Peregrine						
Control	38.1a	13.2b	3.9a	0.50a	3.8a	70
2,4-D (2.5 oz/a)	37.2b	13.5b	3.4b	0.44b	3.6a	0
2,4-D (5 oz/a)	36.6c	12.9c	3.1b	0.42b	3.1b	0
PBI 365	38.0a	14.0a	3.8a	0.48a	2.7b	25
PBI 429	38.1a	14.2a	3.8a	0.47a	1.8c	5
Avg	**37.6**	**13.6**	**3.6**	**0.47**		
PGR	*	*	*	*	Rank (1-5)	%
Norland						
Control	40.2a	12.3b	9.0a	0.63a	2.2b	0
2,4-D (2.5 oz/a)	39.4a b	12.1b	7.2b	0.55ab	4.4a	20
2,4D (5 oz/a)	38.6b	13.1a	6.5b	0.47b	4.3a	70
PBI 365	40.7a	12.5b	8.3a	0.59a	2.1b	5
PBI 429	40.0a	12.3b	8.9a	0.63a	2.0b	5
Avg	**39.3**	**12.5**	**7.9**	**0.57**		
PGR	0.31	0.17	*	0.44		
Atlantic						
Control	49.4	7.1	11.0a	1.2		
2,4-D (2.5 oz/a)	49.2	7.2	9.3b	1.2		
2,4-D (5 oz/a)	50.8	6.8	9.3b	1.2		
PBI 365	49.2	6.8	8.8b	1.2		
PBI 429	50.9	7.6	9.2b	1.2		
Avg	**49.9**	**7.1**	**9.5**	**1.2**		

Values within columns followed by the same letter are not significantly different at P=0.05.

[z] Redness rating from 5 (most) to 1 (least).

% Purchase preference = % of panellists surveyed (n=20) who rated this treatment as most likely to purchase.

*, **,*** Indicate significant at P = 0.05, 0.01 and 0.001, respectively.

Table 2009-3. Influence of plant growth regulators on yields and scab ratings (common and powdery) of Norland, Peregrine and Atlantic potatoes in the Scab Field in 2009.

	Yield	Common (%)	Common Severity[y]	Powdery (%)	Powdery Severity
Cultivar (C)	*	*	**	*	**
PGR (T)	*	*	**	*	**
C*T	0.74	*	**	*	**
Peregrine					
F-Values					
PGR	*	0.66	**	0.09	*
	(T/ha)	**%**	**Severity**	**%**	**Severity**
Control	45.7cd	96	38b	98	60a
2,4-D (2.5 oz/a)	51.2ab	83	20c	94	61a
2,4-D (5 oz/a)	42.5d	93	22c	95	64a
PBI 365	54.0a	99	59a	95	64a
PBI 429	48.6bc	98	65a	79	37b
Avg	**48.4**	**94**	**41**	**93**	**57**
Norland					
PGR	**	*	**	0.42	**
Means					
	(T/ha)	**%**	**Severity**	**%**	**Severity**
Control	42.7a	60b	11a	88	50b
2,4-D (2.5 oz/a)	45.8a	46b	0b	96	74a
2,4-D (5 oz/a)	37.4b	19c	0b	93	79a
PBI 365	42.9a	63ab	0a	93	49b
PBI 429	43.9a	81a	8a	95	54b
Avg	**42.4**	**54**	**5**	**93**	**61**
Atlantic					
PGR	**				
Means					
	(T/ha)	**%**	**Severity**	**%**	**Severity**
Control	43.7a	66ab	7b	76b	23a
2,4-D (2.5 oz/a)	42.2ab	54b	4b	94a	46a
2,4-D (5 oz/a)	38.4b	74ab	16a	75b	32a
PBI 365	45.2a	85a	15a	66b	9b
PBI 429	38.1b	84a	19a	67b	24a
Avg	**41.5**	**73**	**12**	**76**	**27**

Values within columns followed by the same letter are not significantly different at P=0.05.

[z] Ranking of 1 = lightest, ranking of 5 = darkest.

[y] Severity rating represent what % of the tubers would be graded out due to excess levels of the disease

*, **,*** Indicate significant at P = 0.05, 0.01 and 0.001, respectively.

In the 2009 trial, levels of Rhizoctonia were again relatively light and none the PGR treatments influenced Rhizoctonia levels on any of the cultivars tested. This corresponds with previous findings. As in previous trials, the incidence and severity of both common and powdery scab were quite high. The overall incidence and severity of common scab was most intense in Peregrine, least intense in Norland, with Atlantic falling in the middle. In Norlands, treating with PBI 429 appeared to increase the % of tubers affected by common scab relative to the control. **Both rates of 2,4-D significantly reduced grade out of Norland to excess common scab relative to the controls. A similar effect of the 2,4-D reducing grade out to common scab was seen in Peregrine. This effect of 2,4-D treatment reducing common scab levels in red skinned potato cultivars corresponds with the results seen in previous trials.** The degree of mitigation of the common scab was again not related to the rate of 2,4-D applied. In Atlantic, both ABA analog treatments increased grade out to excess scab – this treatment effect was also seen in Peregrine.

The overall incidence and severity of powdery scab was similar in Peregrine and Norland. The Atlantics had less problem with powdery scab than the red skinned cultivars. In Norland, while treatment with 2,4-D appeared to reduce problems with common scab in the 2009 trial, both levels of 2,4-D increased grade out due to powdery scab. This corresponds to the effects of 2,4-D on powdery scab seen in Peregrine in 2008. In Peregrine in 2009, the 2,4-D treatments had no impact on powdery scab, however, treatment with PBI 429 resulted in a significant reduction in grade out to this disease. In Atlantic the PBI 365 treatment reduced loss to excess powdery scab.

General Discussion

The impact of the PGR treatments on yields, crop color and levels of disease showed significant variability from cultivar to cultivar and year to year – this is not surprising given the potential complexity of interactions between environmental conditions, crop growth patterns, pathogen activity and efficacy of an applied treatment. There nonetheless appeared to be some consistent trends;

a) plants treated with 2,4-D had shown a persistent, dosage dependant slowing of vegetative growth and an altered growth habit (erect stems with small cupped leaves). Treatment with the ABA analogs caused no change in the rate or form of plant growth – this was unexpected as corresponding dosages of the analogs applied to other crops had significantly retarded crop development.

b) In most cases the PGR treatments had little impact on yields, but there was a tendency for the high rate of 2,4-D to reduce yields. This was not unexpected as the high rate is double the label recommended dosage. Other researchers have observed a similar dosage dependent reduction in yields following treatment with 2,4-D (Macintosh et al. 1981 and 1982; Rosen et al. 2009).

c) The 2,4-D treatments appeared to increase the number of tubers set per plant, resulting in a small but consistent reduction in average tuber size – this treatment effect has been reported previously (Fults et al 1950; Macintosh et al 1981). A reduction in tuber size could alter the value of the crop – but whether this change is beneficial or detrimental is entirely dependant on market preferences. Enhanced tuber set resulting in small average tuber size would be desirable for seed potato production and we have heard of growers using 2,4-D treatments for

this purpose. Before this treatment can be recommended for use in seed it would be important to check the impact of the 2,4-D on the vigor and yield potential of the seed. In table potatoes there is a wide range of tolerances for size, so a small shift in tuber size distribution would not likely be a major issue. We noted that the panellists tended to not prefer the 2,4-D treated Peregrine tubers despite the apparent colour enhancement provided by this PGR treatment. This suggests that the 2,4-D treatments may be causing some subtle undesirable change in tuber appearance. This change may be something as simple as reducing the average tuber size below some "acceptance threshold" . It should be noted that any undesirable reduction in average tuber size could be easily offset by simply increasing the space between plants, as the tuber size of potatoes is very responsive to manipulation of the plant population.

d) the 2,4-D treatments appeared to alter to skin color of the red-skinned cultivars. This effect was observed immediately after harvest and persisted through 4-5 months of cold storage. The change involved a general darkening of the skin (lower **L** values), with an increase of the amount of blue tones (lower **b** values) in the skin, and a limited of negative effect on the amount of red (**a** values) in the skin color. The change in balance between the various primary colors in the skin was reflected by changes in the **Hue** values – which indicated a shift to a greater preponderance of red/blue relative to yellow/green. Rosen et al. (2009) found a similar change in L and Hue angle values for Norland treated with 2,4-D. They then tested the levels of different anthocyanin-type pigments in the skin and found that the 2,4-D treatments reduced levels of the red pigment pelargonidin (lower **a** values) with a corresponding increase levels of the red-blue peonidin anthocyanin (higher b values).

e) The colorimeter data corresponded with visual assessment of the color, with most visual assessments indicating that the 2,4-D treated tubers were darker and more purplish red than the non-treated tubers. In most, but not all cases, this change in color was considered desirable by panellists.

f) The 2,4-D treatments had little impact on the color of a white skinned cultivar. Banks (2005) found a similar lack of colour change following 2,4-D treatment of white skinned and russet cultivars.

g) Although application of ABA has been used to enhance anthocyanin production in a range of crops, the ABA analogs used in this project did not have any consistent impact on the color of the red-skinned potatoes. Rosen et al 2009 found a similar lack of response when standard ABA was applied to the foliage of Norland potatoes. The lack of response may reflect the use of an insufficient dosage – however we were using concentrations of the ABA analogues that had produced obvious, long lasting changes in the growth and stress tolerance of other crops (Sharma et al. 2004). Dr Abrams of PBI has suggested that the acid form of PBI 365 and 429 should be tested in addition to the ester form used in this project. It is possible that some unique aspect of the chemistry of the potato leaves is inactivating the ester form of the ABA analogs.

h) There was a trend was for the 2,4-D treatments to reduce problems with common scab (*Streptomyces scabies*), with a corresponding but weaker trend for the 2,4-D treatments to increase problems with powdery scab (*Spongospora subterranea*). There have been several previous reports of foliar applied 2,4-D (or similar auxin-like herbicides) reducing levels of common scab in potato. MacIntosh et al. (1981) showed that foliar application of a range of different phenoxy-type auxin analog herbicides reduced common scab – in some cases by a significant amount – but the treatments that were most effective also reduced yields and altered tuber shape and size distribution. As they found that the 2,4-D was not directly effective at controlling infection or growth of the scab organism in pure culture, they speculated that the 2,4-D was instead rendering the potato tubers more resistant to disease. In subsequent field studies Macintosh et al. (1982) further tested a range of concentrations and formulations of 2,4-D for scab control - but found in every case that treatments that provided an effective level of disease suppression also reduced yields and/or crop quality to an unacceptable degree. They speculated that the 2,4-D may be acting as a growth suppressant thereby rendering the potatoes more resistant to scab. They suggested that other growth suppressants like ABA and daminozide should be evaluated as potential scab control agents. However as noted in this project ABA appeared to provide little in the way of scab control – although as noted above we suspect that the dosages used in this study were insufficient for potatoes. In previous studies we had examined the impact of foliar applied daminozide on potatoes grown in a scab infested field but had noted no impact on disease levels (Waterer et al. 1996). Topps et al. (2008) showed that the 2,4-D treatments had no impact on tuber anatomy or physiology (ie; lenticel numbers, lenticel external dimensions, periderm thickness or structure) that could explain this effect. They did however find that the 2,4-D treatment seemed to increase the tubers' tolerance to the thaxtomin A toxin produced by the scab organism. The corky skin lesions characteristic of scab are actually just the potatoes' immune response to this toxin. The 2,4-D treatments did not actually reduce the amount of thaxtomin being produced by the scab organism.

i) It is noteworthy that while the lesions of common and powdery scab are similar in appearance, the physiological mechanisms involved in forming the lesions are very different. One key difference is that powdery scab does not produce an exotoxin like thaxtomin. This difference in toxicity mechanisms may explain why the 2,4-D treatments suppressed common scab but had no impact on powdery scab. We could not find any studies that dealt with the apparent inverse relationship observed between levels of common and powdery scab – ie; treatments that reduced the incidence of common scab actually seemed to make the powdery scab worse. It is possible that the increase in powdery scab is simply reflecting an opportunistic response to an infection field that has been freed from competition by another pathogen. In other research trials we have seen how genetics, climatic conditions (warm versus cool growing season), as well as some crop management variables (like irrigation) appear to shift the balance between the tuber infection by either common or powdery scab. We did not observe any effects of the 2,4-D treatments on crop growth that could explain the apparent shift in the relative sensitivity of the crop to common versus powdery scab.

j) In our studies we noted that the 2,4-D treatments that had the most significant impact on skin colour also had the greatest impact on levels of scab on the tuber surface. There is no information available on the potential linkage between the intensity of skin colour and relative sensitivity to diseases such as scab. We do however have some data supporting this apparent linkage from trials where we were selecting for lines of cv Norland with differing intensities of skin colour (see progress report for ADF Project no. 20070016). In those trials we observed that lighter skinned line selections of Norland appeared to be more sensitive to common scab. There is however no absolute correlation between the intensity of skin colour and sensitivity to scab – this is illustrated by the fact that Atlantics are far lighter in color than either of the red-skinned cultivars, yet they intermediate between the two red types for resistance to common scab and are more resistant to powdery scab than either of the red types. The studies conducted by MacIntosh et al. (1981 and 1982) and Topps et al. (2008) that showed that application of 2,4-D reduced scab were also conducted with white-skinned potatoes.

Summary

Field trials conducted from 2007-2009 suggest that foliar applications of 2,4-D at label recommended dosages can enhance the colour of the cultivars of red-skinned potatoes commonly grown in Saskatchewan with minimal risk of negative impact on crop vigor, yields or tuber quality. The nature and extent of colour change achieved by applying the 2,4-D was influenced by growing conditions and the cultivar being treated. There were also indications that the 2,4-D treatments protected the tubers from common scab, but tended to increase levels of tuber damage by powdery scab. From a grower's perspective the type of scab causing a tuber to be culled is of limited initial importance. If however the 2,4-D treatments are actually causing a shift in scab population or pathogenicity this could have significant ramifications in terms of longterm crop management. While common scab is already widespread across Saskatchewan, powdery scab is more localized. Adoption of 2,4-D treatments may have no net effect on grade out to scab at sites where both types of scab are already endemic, but they should reduce losses at the sites where only common scab is found. Similarly, dryland growers may see greater benefit from the apparent disease control provided by the 2,4-D treatments, as dryland conditions tend to favour common scab rather than powdery. Conversely, irrigated growers interested in improving crop color should be careful as the 2,4-D treatments seem to have the potential to exacerbate the issues with powdery scab that already tend to be more prevalent at wetter sites.

PMRA is presently reviewing performance data to determine whether 2,4-D treatments should be approved in Canada. The results of these trials have been supplied to PMRA. The potential for the 2,4-D treatments to alter the disease sensitivity of the crop may be of interest to PMRA.

Project Objectives - the project followed the stated objectives except ... a) we did not test the impact of application of the PGR's more than twice in a season and b) the observation that the 2,4-D treatments were significantly reducing common scab while also increasing powdery scab merited more close examination. We felt that the issue of time and number of applications was adequately addressed in the recent publication by Rosen et al. (2009) who showed no efficacy of PGR treatments applied either before the onset of tuber set or later than 30 days from the onset of tuber set. They also found that adding a 3rd or 4th application of 2,4-D had no beneficial effect on colours but resulted in an incremental loss of yield. The discovery of the 2,4-D effects on common scab was unexpected – although not without precedent (MacIntosh et al 1981 and 1982; Topps et al. 2008). There are however no previous reports of 2,4-D increasing problems with powdery scab. We considered further exploration of this apparent secondary effect of the 2,4-D treatments worthy of re-directing a portion of the research effort, especially as both common and powdery scab are widespread in potato fields across Saskatchewan.

Project Related Extension Activities

- over the course of the 2008 and 2009 growing season, the test site was visited by several growers interested in using 2,4-D for colour enhancement.
- the trial results were presented at the Annual Meeting of the Saskatchewan Vegetable Growers Association (Nov 2008 and Nov 2009)
- the trial results were presented at the Annual Meeting of the Saskatchewan Seed Potato Growers Association (Dec 2008)
- the trial results from 2007, 2008 and 2009 were provided to PMRA for inclusion in the efficacy data set being prepared in anticipation of registration of 2,4-D for use in Canada

The trial results were published on the University of Saskatchewan Vegetable Crops Research Program Website :
www.usask.ca/agriculture/plantsci/vegetable/resources/publication/2008resources/Plant_growth_regulators.pdf

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Staffing

2008 - Danielle Stevens and Laurie Thomson – part time summer student assistant
2009 – Trung Lee – part time summer student assistant

Budget

A detailed summary of project expenditures will be provided by the Research Accounts Office at the University of Saskatchewan

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